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Final Report--DNRC Grant ARE 445-811

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Energy and Biomass Potential of Cattails in Montana

Final Report--DNRC Grant ARE 445-811

November 1985

submitted by: Stanley M. Wiatr, Ph.D.
Associate Professor of Biology
Department of Biological Sciences
Eastern Montana College
1500 North 30th Street
Billings, Montana 59101-0298

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INTRODUCTION

The genus Typha is an emergent macrophyte inhabiting brackish and freshwater habitats throughout the world (Good 1953; Polunin 1960). Three species are native to North America: T. latifolia, T. angustifolia and T. domingensis (McNaughton 1966). T. glauca, a sterile hybrid between T. latifolia and either of the other two species, has also been reported (McNaughton 1966). Of these species, T. latifolia appears to be the only one found throughout most of the Rocky Mountain region, particularly Montana (McNaughton 1966; Hahn 1973). However, Hitchcock and Cronquist (1973) suggested that much Montana material may be intermediate between T. latifolia and T. angustifolia, i.e., probably a T. glauca hybrid.

The vegetative biomass of Typha consists of several long, sword-shaped leaves attached to jointless stems usually submerged in shallow water. Floral structures often observed among the leafy biomass consist of thousands of pistillate flowers producing nutlets and down compressed in a terminal brown spike. Most of the underground biomass consists of an extensive, anastomosing system of rhizomes at various depths below the surface of the soil. Roots are also present, through less abundant, and usually located at the base of floral or vegetative stalks.

Comparative estimates of primary productivity in different ecosystems suggest that the upper limit of plant productivity is 50-80 metric tonnes of dry matter per hectare per year. Such high productivity can only be achieved in tropical reedswamps or through intensive agriculture of perennial plants in tropical environments. In less equable, temperate climates the maximum productivity is lower. Typically, reedswamps are

among the most productive temperate ecosystems with annual productivity ranging from 30 to 45 metric tonnes of dry matter per hectare (Westlake 1963). As indicated in Table 1, temperate reedswamp productivity compares favorably with other less productive but economically important ecosystems such as coniferous forests (28 tonnes per hectare per year) and cultivated perennial plants (30 tonnes per hectare per year).

Productivity data for several Typha species are given in Table 2. Mean productivity values for all species cited in Table 2 are 13.7 tonnes per hectare per year for rhizomes, 14.4 tonnes per hectare per year for shoots, and total mean productivity of 26.7 tonnes per hectare per year. The wide range of total productivity (6.4 to 59 tonnes per hectare per year) can be attributed to interspecific variation and differences in sampling methodology, site selection, and seasonal variation in productivity.

The inherent difficulty associated with harvesting cattail rhizomes has often led to estimates of rhizome production. Annual production of rhizome biomass has been estimated to equal annual shoot production (Westlake 1975). Boyd (1971) found rhizome production to approximate 53.5% of the total annual biomass production while McNaughton (1966) reported a comparable value of 50% or more. In contrast, Fiala's (1973) study of productivity and biomass apportionment indicated that the relationship between rhizome and shoot production in Typha is not constant. For example, at the end of the first growing season, rhizomes of T. latifolia were equivalent to 94.3% of the total aerial biomass. At the end of the second season, however, rhizome biomass was only 28.3% of the aerial biomass. Similar observations were reported for T. angustifolia in Fiala's study.

In contrast to most studies attempting to determine cattail productivity in natural stands, Fiala (1973) used young cattail seedlings initially weighing 2-5 grams to study cattail productivity over time. At the end of the second growing season, each plant had a mean annual productivity of 23.6 kg. Approximately 55% of the total biomass was underground and consisted of shoot bases, live rhizomes, dead rhizomes and roots. Live rhizomes made up 18.1% of the total biomass at harvest. In a parallel study with T. angustifolia, the annual productivity was 13.9 kg per plant, with 19.3% of the total biomass consisting of live rhizomes.

Standing crop data have been used extensively to assess the production potential of Typha species. As indicated in Table 3, mean standing crops derived from several studies are 22.7 tonnes per hectare for rhizomes, and 15.6 tonnes per hectare for shoot biomass, thus giving a mean total standing crop of 32.5 tonnes per hectare. The wide ranges for the means in Table 3 are noteworthy since they reflect species differences, climatic, edaphic, and sampling variation. A comparison of the mean values in Table 3 with productivity values in Table 2 suggests that the standing crop of shoot biomass gives a close approximation of shoot productivity (15.6 vs. 14.4 tonnes). In contrast, standing crop values for rhizome biomass overestimate annual productivity of biomass component by 93%, i.e., annual productivity of rhizome biomass would be approximately 60% of the standing crop.

Economic uses of cattails have been reviewed (Marsh 1955; Reed and Marsh 1955; Morton 1975). Cattail leaves have been used to calk wooden barrels, in the construction of chair seats, in paper making and as a cotton substitute. Fertile spikes of cattail contain 17% oil with a high linoleic acid content (Reed and Marsh 1955). The extensive rhizomes of

cattails are noteworthy due to a high biomass yield and a high starch content ranging from 15% to 25% (Fiala 1978; Boyd 1971; McNaughton 1966). Using the mean productivity data for Typha rhizomes in Table 2, the estimated annual starch yield of Typha would be 2.1 to 3.4 tonnes per hectare. Since fermentation of cattail rhizome starch has been reported (Reed and Marsh 1955; Perez-Arbelaez 1956), conversion of cattail starch to ethyl alcohol is also feasible.

The objective of this study was to evaluate the biomass potential of selected Typha populations found in southcentral Montana. In the context of this study, "biomass potential" refers to the total yield of plant biomass with respect to energy content and "crop" components consisting of oils, polyphenols, sugars, starchs, lignin and crude fiber.

MATERIALS AND METHODS

Biomass harvests - Two cattail marshes located in southcentral Montana were selected for repetitive harvests at approximately 5 week intervals throughout the 1982 growing season. The first site, designated West Billings, was a 5 acre marsh located approximately 7 miles west of Billings, Montana, at the southeast corner of 72nd Street West and the Laurel Airport road. Gravel was generally found 20-30 cm below the surface of this marsh. The water level at this site fluctuated from 5 to 20 cm above the rhizomes. The second site, designated Park City, was located 5 miles west of Park City, Montana, between the frontage road parallel to Interstate 90 and railroad tracks approximately 200 meters south of the frontage road. It consisted of a well established stand of approximately 20 acres of cattails.

Four destructive harvests of all biomass were made at each site. Each harvest consisted of six, 1 m^2 plots from one area of the marsh. Although no attempt was made to randomize the plots selected at the site, each plot was at least 2 meters away from all others. Above-ground biomass was clipped at water/soil level. Below-ground biomass was then harvested with a post spade to a depth of 20-40 cm. The objective was to remove all live rhizomes and associated biomass which were ordinarily well-stratified between 10-40 cm. All rhizomes were initially washed with water under pressure to remove soil and debris. During a second washing, the rhizomes were segregated into living or dead growth as described below. All fresh biomass was weighed, then air dried at 20-30 C to constant weight, and reweighed on an Ohaus heavy duty balance for dry weight determination.

Biomass components were subdivided into above-ground material consisting mostly of leaves, and below-ground material consisting of shoot/leaf bases, roots, live rhizomes and dead rhizomes. The dead rhizomes were further segregated from other underground organs on the basis of color. The inner tissues of live rhizomes were characteristically white due to their starch content, while similar tissues in dead rhizomes varied in color from orange to black. This method of identifying new vs. old growth in rhizomes has been used previously (Bernard and Bernard 1973).

ANALYSES

Biomass samples were first reduced in a Wiley mill to pass through a 1 mm mesh screen. Methods of extraction, chemical analyses, calorimetric determinations and statistical comparisons have been described previously (Wiatr 1985). A summary of the analytical methods is given in Appendix 1.

RESULTS AND DISCUSSION

Standing Crop - Standing crop is the total biomass present at harvest, and comprises living biomass of the current season and dead biomass from preceding years. As indicated in Table 4, the maximum standing crop was found in late August at both sites: the Park City site had a maximum standing crop of 59.8 tonnes per hectare while the West Billings site had 41.0 tonnes per hectare. At this time, 62% of the biomass was derived from above-ground biomass and living rhizomes. The remainder was apportioned between dead rhizomes (16%) and standing dry matter (22%) from previous years. At the West Billings site, a larger percentage (86.6%) of the total biomass consisted of above-ground biomass and living rhizomes. Dead rhizomes made up 9% of the total biomass at harvest while standing dry matter made up the remaining 4%.

With the contribution of dead rhizomes and standing dry matter subtracted from the total biomass present at each harvest, a progressive increase in "live" biomass (defined as the sum of above-ground live biomass + live rhizomes) was evident from early spring through late August at both sites. The total biomass was greater at the Park City site (59.8 vs. 41.0 tonnes per hectare), but both sites had similar combined yields of living biomass. This indicated that the apportionment of carbon within biomass components of the cattail marshes varied substantially.

The maximum yield of living biomass was 36.7 tonnes per hectare for Park City and 35.5 tonnes per hectare for West Billings. Although these yields were quite similar, a greater percentage of carbon was allocated to living rhizomes at the Park City site. Living rhizomes obtained from Park City made up 69% of the total living biomass while live rhizomes from West

Billings made up 50%. This indicates that the relationship between above-ground standing crop and below-ground yield of living rhizomes is not constant and thus may have limited predictive value.

A late season decline in combined yield of live rhizomes and above-ground biomass was observed at both sites. At the Park City site, the decrease was due entirely to a reduction in above-ground biomass, particularly seasonal leaf senescence. A seasonal decline in above-ground biomass was also observed at the West Billings site, but a compensatory increase in dry weight of living rhizomes also occurred. These observations are consistent with the interpretation that carbon was transported from above-ground biomass to below-ground biomass at West Billings but not Park City. The basis of this difference is not known, although abrupt microclimatic variation at the Park City site may have been an important factor influencing carbon transport late in the growing season.

Productivity - Annual productivity is the total biomass produced in one growing season. It is an important value that allows a comparative assessment of productivity in cattails with conventional, annual crops. An indirect estimation of annual productivity is necessary when evaluating established cattail marshes because of the perennial nature of the marsh ecosystem. Estimates of annual productivity in Typha from studies of both standing crop and productivity suggest that the annual yield of below-ground biomass is roughly equivalent to the maximum standing crop of above-ground biomass (McNaughton 1966; Boyd 1971; Fiala 1973). As indicated in Table 5, the total annual productivity of Typha would then be 18.0 tonnes per hectare at the Park City site and 30.6 tonnes per hectare at the West Billings site. The estimate of productivity at the West Billings site is approximately 14% less than the empirically determined combined standing crop of above-ground

biomass and live rhizomes (30.6 vs. 35.5 tonnes per hectare). The estimate of annual production calculated for the Park City site was approximately 50% less than the combined standing crop of above-ground biomass and live rhizomes (18.0 vs. 36.7 tonnes per hectare). Collectively, these values indicate that the annual productivity of cattail marshes in southcentral Montana is 18 to 30 tonnes per hectare, whereas the maximum standing crop (inclusive of all organic matter) is 40 to 60 tonnes per hectare.

Oils, polyphenols and hydrocarbons - Data on the content of oils, polyphenols, and hydrocarbons are given in Tables 6 and 7. The oil content of all types of biomass sampled throughout the growing season never exceeded 2.4%. Generally, above-ground biomass and live rhizomes had an oil content (0.9% to 2.4%) greater than dead rhizomes and standing dry matter (0.5% & 1.9%).

The polyphenol content of *Typha* biomass was 1.0% to 3.2% in standing dry matter and dead rhizomes, and 2.4% to 11.5% in above-ground biomass and living rhizomes. Live rhizomes from the Park City site had an exceptionally high polyphenol content, regardless of harvest date. Seasonal trends in polyphenol content were not evident.

Hydrocarbons were found in trace quantities. They represented a minor chemical constituent for all biomass types throughout the growing season.

Lignin, crude fiber and ash - Determinations of lignin (Table 8), crude fiber (Table 9) and ash (Table 10) indicated that these substances collectively are major constituents of the residue remaining after extraction of oils, polyphenols, and hydrocarbons. Approximately 50% of the above-ground biomass, dead rhizomes and standing dry matter was lignin. Live rhizomes contained 25% lignin.

Crude fiber content was less than lignin content for all biomass types. In above-ground biomass and standing dry matter the crude fiber content ranged from 33% to 38% while dead rhizomes had somewhat less (23% to 25%). The lowest crude fiber content (16%) was found in live rhizomes.

The ash content of Typha biomass ranged from 5.5% to 7.6% at Park City and 9.6% to 14.5% at West Billings. Typha samples from West Billings had approximately a two-fold greater ash content than comparable forms of biomass from Park City. The reason for this variation is not known.

Sugars - Sugar content data are given in Table 11. The highest sugar content was found in live rhizomes. The mean value for all live rhizome harvests at the Park City site was 8.1% with a seasonal high of 10.2% in the August harvest. Live rhizomes from West Billings had less sugar (mean of 5.4%) with seasonal values ranging from 3.5% to 6.4%. The sugar content of above-ground biomass did not exceed 2.7% at either site, with a range of 0.5% to 2.7% for Park City and 0.8% to 2.2% for West Billings. The sugar content of dead rhizomes and standing dry matter was negligible.

Starch - Starch content data are given in Table 12. All biomass types contained starch, but the greatest accumulation was always in live rhizomes, regardless of harvest date. Live rhizomes from both sites had in excess of 20% starch at the end of the growing season. The starch content of live rhizomes harvested from Park City increased from May to June, then remained constant through the remainder of the growing season. Similar biomass from the West Billings site experienced a late June drop in starch content, followed by a progressive increase to a seasonal maximum of 23.7% in October.

The leaf/stem bases and root biomass included with "live rhizomes" had a dilutive effect on starch content in rhizomes per se. As indicated in Table 12, after removal of roots and leaf bases, the live rhizomes had a starch content of 28.3% in contrast to 20.4% in live rhizomes with associated roots and leaf bases.

Dead rhizomes and standing dry matter may represent significant components of the total starch reserves in well-established Typha ecosystems. At the end of the growing season, dead rhizomes had 15% to 39% of the starch content found in living rhizomes. Standing dry matter had 100% of the starch content of above-ground biomass. These observations suggest that starch mobilization from leaves to rhizomes late in the growing season is an incomplete process. Abrupt changes in local weather such as a premature frost or snowfall may stop translocation of photosynthetically produced sugars while starch synthesis in the leaves could continue.

Protein - Estimates of protein content in Typha biomass are given in Table 13. Live rhizomes from both sites had a mean protein of 7.6%. Above-ground biomass had a mean protein content of 5.8% while dead rhizomes and standing dry matter had respective protein contents of 4.1% and 2.4%. All biomass types from the West Billings site had 37% to 156% more protein than comparable biomass from the Park City site.

Crop yield - Standing crop data for all extractables and insoluble materials are given in Table 14. Oils from Typha biomass would be the least attractive resource since total oil yield from all biomass was very low, typically less than 1 tonne per hectare.

The total yield of polyphenols, sugars and protein derived from all biomass at harvest was generally in excess of 2 tonnes per hectare. The

yield of these materials could be characterized as low to moderate.

Starch was a moderate biomass component since the mean yield from both sites was in excess of 6 tonnes per hectare, with a range of 5.5 to 8.1 tonnes per hectare for the two sites. Live rhizomes contained 70-87% of the total starch from all biomass.

Crude fiber and lignin were the greatest biomass components with mean yields of 12.0 and 17.7 tonnes per hectare, respectively. Together, these substances represented 68% of the total biomass at harvest.

The standing crop data in Table 14 overestimate annual yield since the age of the cattail stand is not considered. In Table 15, annual productivity of the chemical constituents in Typha biomass has been estimated from the yield data for above-ground biomass and live rhizomes. The annual yield of polyphenols would be approximately 1.3 tonnes per hectare. About 1.1 tonnes per hectare of sugars would be derived from above-ground biomass and live rhizomes. The annual yield of starch would be 3.9 tonnes per hectare or 68% of the starch present in the standing crop. Crude fiber (5.8 tonnes per hectare) and lignin (6.5 tonnes per hectare) would have annual yields much less than standing crop values since dead rhizomes and standing dry matter would not contribute to productivity expressed on an annual basis.

Potential Alcohol - Estimates of potential ethanol yield from standing crop harvest of above-ground biomass and live rhizomes are given in Table 16. The combined ethanol yield from starch and sugars derived from above-ground biomass and live rhizomes would be 1171 gallons per hectare. Approximately 70% of the ethanol or 824 gallons per hectare would be derived from starch in live rhizomes. Sugars in live rhizomes would contribute another 20% or 239 gallons per hectare. Living rhizomes

from an October harvest would contain slightly more than 90% of the fermentable carbohydrates at harvest.

As discussed in the introduction, standing crop data overestimate annual productivity. Ethanol yields based on annual productivity indicate that the maximum amount of ethanol produced annually per hectare of cattails (above-ground biomass + living rhizomes) would be 818 gallons (Table 17). As a sole source, living rhizomes would annually produce 82% of the fermentable carbohydrates equivalent to 673 gallons of ethanol per hectare. In either case, starch derived from live rhizomes is 65% of the total fermentable carbohydrates from above-ground biomass and living rhizomes. Consequently, rhizome starch was the single most abundant source of fermentable carbohydrate in Typha biomass.

The potential annual ethanol yield per acre from live rhizomes is substantially less than estimates for beets, but greater than estimates for cereal grains (Theurer et al 1981; Wiatr 1985). As indicated in Table 18, sugar beet cultivars produce fermentable carbohydrates equivalent to 1132-1851 gallons of ethanol per hectare. Fuel beets, i.e., those cultivars selected for a high tonnage of fermentable carbohydrates, would have a somewhat greater potential ethanol yield. Corn and dryland wheat and barley would have a much lower potential ethanol yield per hectare, but possibly a greater total ethanol yield on a statewide basis due to the much greater acreage available for dryland farming in Montana.

Comparative mass yield - Data on comparative mass yields of cattails and crops commonly grown in Montana are given in Table 19. The total annual yield of photosynthetically-fixed carbon in cattails would be approximately 26.8 tonnes per acre. This would be similar to the annual productivity of sugar beets or fuel beets in Montana. It would also be

275-500% greater than the productivity of cereal grains grown in Montana.

Since cattail rhizomes contain a fairly high percentage of starch, the rhizomes could be considered the "crop" component of cattail biomass. The crop yield of cattails would then be 16.1 tonnes per hectare, or about 60% of the total biomass yield. Sugar/fuel beets have a mean crop yield of 17.5 tonnes per hectare or 82% of the total biomass yield. Cereal grains have a mean crop (grain) yield of 2.9 tonnes per hectare or 37% of the total biomass yield. Cattails divert less carbon to crop yield than beets, but more than cereal grains.

A comparison of crop yield can be refined further by considering only the yield of fermentable carbohydrate associated with the crop components. The fermentable carbohydrate yields given in Table 19 were derived from the combined yield of starch and total sugars in cattail rhizomes, beet roots or cereal grain. The annual yield of fermentable carbohydrates in cattail rhizomes was 4.7 tonnes per hectare. This would be equivalent to 33% of the yield in beets and 220% of the yield in cereal grains.

Residual cattail biomass consisting of leaves and rhizomes depleted of fermentable carbohydrates represents 82% of the total biomass. Beets have 38% residual biomass while cereal grains have 73%. Cattails therefore divert a greater percentage of photosynthetically reduced carbon to residual biomass than conventional crops. The crop value of cattails could be enhanced through a breeding program favoring larger rhizomes with a greater starch content and cultivars with less leaf biomass. A 100% increase in crop yield and a 50% increase in the content of fermentable carbohydrates would be necessary to obtain the existing yield of fermentable carbohydrates in fuel/sugar beets. The extent to which Typha could be genetically or agronomically manipulated to achieve this goal is

not known.

Energy Content - Calorific values for *Typha* biomass components are given in Table 20. The energy content of biomass ranged from 3548 to 4085 calories per gram. Oils from both sites had a mean calorific value of 8559 calories per gram while polyphenols had a mean energy value of 5655 calories per gram. The residue remaining after extraction of oils and polyphenols had a mean energy content of 3938 calories per gram. The values given here for biomass components, extractives and residual biomass are consistent with previously reported values (Wiatr 1985).

Energy apportionment - Table 21 gives the distribution of energy in *Typha* biomass (standing crop) as a function of biomass type, i.e., above-ground biomass, live rhizomes, dead rhizomes or standing dry matter. The maximum total energy derived from all biomass was 23.9×10^7 kilocalories per hectare for Park City and 15.3×10^7 kilocalories per hectare for West Billings. These maximum values occurred in late August, concurrent with maximum biomass yields. The October energy harvest of all *Typha* biomass was 94% of the seasonal maximum at Park City and 98% at West Billings. When calculations were restricted to living biomass (above-ground biomass and living rhizomes), the same relationship held. At the end of the growing season, living biomass made up greater than 50% of the total energy at harvest (57% at Park City and 82% at West Billings).

The energy content data given in Table 21 further indicate wide seasonal variation in energy distribution in *Typha* biomass. For above-ground biomass, the maximum energy yield occurred in late August at both sites. Live rhizomes at the Park City site had a seasonal maximum in early spring while the maximum energy associate with live rhizomes at the West Billings site occurred in late June. The variation observed in energy

yield in living biomass is probably related to the movement of reserve food materials from below-ground to above-ground organs in early summer, and the attainment of maximum photosynthesis with the maturation of above-ground biomass in late August.

The net energy gain in living biomass was calculated as the energy difference in all living biomass at the first and last harvest. The Park City site had a net energy gain in living biomass of 1.0×10^7 kilocalories per hectare while the West Billings site gained 4.3×10^7 kilocalories per hectare.

Data on the seasonal distribution of energy and its apportionment into selected biomass types are given in Tables 22 and 23. Energy gained in living biomass at the end of the growing season was apportioned for the Park City site as follows: oils, 2%; polyphenols, 11%; residual biomass, 86%. Values for West Billings were: oils, 4%; polyphenols, 4%; residual biomass, 92%. It is evident that most of the energy in _Typha_ biomass at the end of the growing season is diverted into the residual biomass remaining after oils and polyphenols have been extracted. As discussed earlier, the residue contained sugars, starch, lignin, crude fiber, and ash.

The pattern of energy flow in the _Typha_ marsh at the Park City site suggests a dynamic but stable ecosystem. Above-ground biomass experienced a net energy gain in oils, polyphenols, and residual biomass. However, these gains were offset at the whole plant level through energy losses in live rhizomes. The combined net energy gain for above-ground biomass and live rhizomes was approximately 7.6×10^6 kilocalories per hectare. When consideration of energy flow is expanded to include dead biomass as well, then the gain of 7.6×10^6 kilocalories per hectare in living biomass was

offset by a net loss of 7.6x10^6 kilocalories per hectare in dead biomass. The net energy increase for the Typha marsh at the Park City site was zero, and this value suggests that this marsh is a stable ecosystem where the gain in energy in living biomass through photosynthesis was balanced by a loss of energy through decomposition, grazing, and other processes.

The pattern of energy flow in the Typha marsh at the West Billings site was indicative of a dynamic, unstable ecosystem. This marsh differed from the Park City site principally because a net increase in energy was observed for the ecosystem at the end of the growing season. As indicated in Table 23, living biomass had an energy gain of 42x10^6 kilocalories per hectare compared to an energy increase of 35x10^6 kilocalories per hectare for combined living and dead biomass. The difference of 7x10^6 kilocalories per hectare was likely due to energy losses through decomposition, foraging, and other processes. This difference is essentially the same observed for the Park City marsh, and suggests that the rate of energy loss was the same for both. The West Billings site as a whole is considered unstable because of the net gain in reduced carbon equivalent to 35x10^6 kilocalories per hectare, primarily in the form of residual above-ground biomass. The only other component having a positive energy gain would be oils which represented a relatively small percentage (8%) of the total energy gain. Factors responsible for the instability of the West Billings marsh contribute to its greater productivity and the nature of these factors should be investigated. Although the West Billings marsh had a total biomass energy equivalent to 60% of the energy in the Park City marsh, it was, nevertheless, more productive due to a net energy gain at the end of the growing season. Viewed in another context, relative productivity could be expressed as the net energy gain (before

losses alluded to earlier) divided by the mean energy in living biomass throughout the growing season. Expressed in this way, the Park City marsh had a relative productivity of 5.4%. In contrast, the relative productivity of the West Billings marsh was 36.0%.

Comparative energy yield - Comparative energy yield data for selected Montana crops are given in Table 24. Cattails divert a greater percentage of energy to food reserves than cereal grains, but less than fuel beet or sugar beet cultivars. The energy in fermentable carbohydrates derived solely from cattail rhizomes is 1.7-2.7x10^7 kilocalories per hectare. This energy value represents approximately 18% of the total energy at harvest, based on an annual energy yield of 8.7x10^7 kilocalories per hectare. Per unit area, the energy yield from fermentable carbohydrates in cattail rhizomes would be equivalent to 30-37% of the yield in beets and 210% of the yield in cereal grains.

The lack of a positive correlation between maximum available energy and crop yield presents something of an agronomic dilemma. From the perspective of maximum harvestable energy in the cattail marsh, a late August harvest would be reasonable. However, selection for starch in living rhizomes would favor an October harvest since the maximum starch yield would be present at this time. The type of resource derived from Typha (e.g., starch vs. biomass for combustion) would have to be identified in order to determine an appropriate harvest period. The energy yield from fermentable carbohydrate-depleted rhizomes and above-ground biomass (leaves) in cattails greatly surpasses the energy associate with equivalent biomass in beets and cereal grains. The energy yield per hectare of 4.0x10^7 kilocalories from rhizome residue in cattails is 330% greater than the energy yield from beet pulp and 2000% greater

than the residue from cereal grains. Similarly, the energy yield of cattail leaves per hectare is 15.8×10^6 kilocalories, a value 278% greater than beet leaves and 180% greater than straw or stover from cereal grains.

On a per acre basis, the comparisons of mass and energy yield indicate that cattail productivity in Montana marshes would be highly competitive with the productivity of conventional crops. However, total annual production of cattails in Montana would likely be much less than current production of crops such as sugar beets and wheat due simply to the large acreage presently devoted to these conventional crops. In 1982, 1.73×10^6 acres of cropland in Montana were irrigated (Anon 1983). Use of 5% of this land or possibly adjacent marginal cropland for cattail production would generate 1.65×10^5 tonnes of fermentable carbohydrates. Since 6.35 kg of fermentable carbohydrates are required to produce one gallon of ethanol, cattails would produce the equivalent of 26 million gallons of ethanol annually. It is very unlikely that cattails could or should displace sugar beets as an irrigated crop since the yield of fermentable carbohydrates from beets is approximately threefold greater than cattails. Marginal cropland located in areas where the water table is at or near the soil surface would favor cattail production, particularly if the residual biomass (depleted of fermentable carbohydrate) had some economic value.

The attractiveness of cattails as a crop plant is diminished by the comparatively low percentage of energy diverted to fermentable carbohydrates. On a total yield basis, fermentable carbohydrate production in cattails would be greater than wheat and barley, equivalent to corn, and less than sugar beets. The "crop" potential of cattails

could be enhanced through genetic selection for cultivars with a greater yield of fermentable carbohydrates in rhizomes. In contrast to crop plants, cattails appear to divert a disproportionately large amount of energy to residual biomass and leaves rather than food storage. The selective advantage of this strategy may be related to maintenance of the marsh ecosystem through nutrient recycling and energy flow through the decomposition of leaves and starch-depleted rhizomes. Cultivation of cattails would eliminate the need for nutrient recycling and marsh longevity such that artificial selection could favor cultivars that divert more energy to food reserves (e.g., rhizome starch) rather than ecosystem maintenance.

CONCLUSIONS

Established cattail marshes in southcentral Montana are energy-rich renewable resources. The standing crop biomass yield of 40 to 60 tonnes per hectare exceeds the total yield of important crops in Montana such as sugar beets by 200% and wheat or barley by 700%. A mature cattail marsh, however, is the product of several years of growth and development. Consequently, standing crop is not equivalent to annual productivity. Also, the variation in biomass composition among crops requires that energy yield at harvest be used as the basis for comparison. Viewed in this context, the mean annual energy yield of cattails ($11.1\text{x}10^7$ kilocalories per hectare) would be 50% greater than high-yielding sugar beets and nearly 300% greater than wheat or barley grown in Montana. From the perspective of annual energy yield in the form of photosynthetically reduced carbon, cultivation of cattails as a renewable energy crop would be justified.

Although starch is a major food reserve material in cattail rhizomes, it is not present in sufficient quantities to compete with sucrose yield in sugar/fuel beets. Potential ethanol yield from all living biomass in a well-established cattail stand would be 1171 gallons per hectare. However, a biomass conversion program would in all likelihood use starch produced annually in cattail rhizomes as the feedstock for ethanol production. Rhizome starch alone would then produce the equivalent of 673 gallons per hectare of ethanol annually. Since sugar/fuel beet cultivars can currently produce sucrose equivalent to 1200-2200 gallons of ethanol per hectare annually (Theurer et al 1981; Wiatr 1985) harvesting cattail rhizomes solely as a feedstock for ethanol production would not be a sound economic practice.

Regarding cattails as a multiple-use crop would serve to enhance and maximize the utility of this species as a renewable resource. Residual protein in biomass depleted of fermentable carbohydrates should be evaluated as a potential livestock feed since 2 to 3 tonnes of protein would be derived annually per hectare of biomass. Lignin and crude fiber are clearly major constituents of cattail biomass. Possible uses of these materials include thermochemical liquifaction into oil (Elliot 1981), gasification into fuel (Soltes et al 1982), and production of industrial chemicals (Levy et al 1981; Lipinsky 1981). Long term goals should be directed towards genetic selection for increased starch content in rhizomes, increased rhizome biomass and reduced leaf biomass.

TABLE 1: ESTIMATED PRIMARY PRODUCTIVITY OF SELECTED FERTILE SITES
(from Westlake 1963)

Temperate Ecosystem	Productivity (tonnes per hectare per year)	Range (+ %)
Freshwater Submerged macrophytes	6	20
Deciduous	12	25
Terrestrial herbs	20	25
Agriculture-annuals	22	15
Coniferous forest	28	25
Agriculture-perennials	30	20
Reedswamp	38	20

TABLE 2: PRODUCTIVITY OF TYPHA (dry weight)

PRODUCTIVITY (tonnes per hectare per year)

Species	Rhizomes	Shoot	Total	References
T. latifolia	10.7[1]	10.7	21.4[1]	Pearsall and Gorham 1956
	15.3[1]	15.3	30.6[1]	Penfound 1956
	13.6[1]	13.6	27.2[1]	Harper 1918
	7.3	8.3	15.6	Dykyjova,et al 1971
	11.9	15.4	27.3	Dykyjova, et al 1971
	14-26	11-33	25-59	Kresovich et al 1981
T. angustifolia	17.3[1]	17.3	34.6[1]	Harper 1918
	2.8	3.4	6.4	Dykyjova, et al 1971
	11.4	13.6	25.1	Dykyjova, et al 1971
T. glauca	13.1[1]	13.1	26.2[1]	Bernard and Fitz 1971
T. spp.	14.4-16.8[1]	14.4-16.8	28.8-33.6[1]	Bray et al 1959
	20-30[1]	20-30	40-60[1]	Westlake 1975
	-	-	12.4	McNaughton 1966
	-	-	22.1	McNaughton 1966
			29	Westlake 1963
Mean	13.7	14.4	26.7	

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[1] Values with superscripts are estimates based on the relationship that the annual underground increment equals the biomass of aerial shoots (see Westlake 1975).

TABLE 3: STANDING CROP ESTIMATES OF TYPHA SPP.

	STANDING CROP (tonnes per hectare)			
Species	Rhizomes	Shoot	Total	References
T. latifolia	-	10.7	-	Pearsall and Gorham 1956
	6.8	-	-	Reed and Marsh 1956
	-	6.8	-	Boyd 1970
	-	4.3-22.5	-	Boyd and Hess 1970
	-	-	10.9	Grace and Wetzel 1981
	17.8	33.6	53.4	Dykyjova et al 1971
T. angustifolia	-	-	21.0	Grace and Wetzel 1981
	51.9	29.0	80.9	Dykyjova et al 1971
	-	11.2	-	Mason and Bryant 1975
		15-35		Westlake 1975
T. glauca	-	13.7	-	Bernard and Fitz 1979
	-	21.1	-	Van der Valk and Davis 1978
	65.2	-	-	Reed and Marsh 1956
	9.5	10.3	19.8	Bernard and Bernard 1973
Other Typha spp.				
	9.1	4.0	13.1	McNaughton 1966
	8.9	3.8	12.7	McNaughton 1966
	5.6	4.2	9.8	McNaughton 1966
	8.0	7.3	15.3	McNaughton 1966
	26.5	13.4	39.9	McNaughton 1966
	29.6	16.8	46.4	Westlake 1963
	-	16.7	-	Jervis 1969
	26.5	14.4	40.9	Bray et al 1959
	29.6	16.8	46.4	Bray et al 1959
	-	3.8-13.4	-	McNaughton 1966
	22.9	21.1	44.0	Howard-Williams 1973
	-	35-47	-	Kaul 1971
Mean	22.7	15.6	32.5	

TABLE 4: SEASONAL VARIATION IN STANDING CROP

STANDING CROP (d.w. tonnes per hectare)

Harvest Date	Aboveground	Rhizomes Live	Rhizomes Dead	Standing Dry Matter	Aboveground + Live Rhizome	Standing Crop (Aboveground, all Rhizomes, Standing Dry Matter)
PARK CITY						
5/15	0	30.3	8.4	19.1	30.3	57.8
6/30	2.9	28.5	11.0	17.3	31.4	59.7
8/27	11.4	25.3	9.8	13.3	36.7	59.8
10/2	6.6	25.8	8.9	14.9	32.4	56.2
WEST BILLINGS						
4/24	0	22.4	4.7	4.3	22.4	31.4
6/28	2.7	25.1	4.3	7.1	27.8	39.2
8/30	17.7	17.8	3.7	1.8	35.5	41.0
10/9	12.9	20.3	4.9	2.3	33.2	40.4

TABLE 5: ESTIMATED ANNUAL PRODUCTIVITY

	PRODUCTIVITY (tonnes per hectare per year)		
Site	Aboveground Biomass	Rhizomes	Total
Park City	6.6	11.4	18.0
West Billings	12.9	17.7	30.6
Mean	9.8	14.6	24.3

TABLE 6: OILS, POLYPHENOLS AND HYDROCARBONS
PARK CITY SITE

Harvest Date & Biomass Type	YIELD (% DRY WEIGHT) Oils	Polyphenols	Hydrocarbons	Residue
Aboveground				
6/30	1.8	3.0	0.1	95.1
8/27	0.9	7.1	0.1	91.9
10/2	1.4	3.5	<0.1	95.1
Live Rhizomes				
5/15	1.3	11.5	0.1	87.1
6/30	1.2	10.1	0.1	88.6
8/27	1.5	8.2	<0.1	90.3
10/2	0.8	10.9	<0.1	88.3
Dead Rhizomes				
5/15	0.5	3.0	<0.1	96.5
6/30	0.9	1.8	<0.1	97.3
8/27	1.1	1.6	<0.1	97.3
10/2	1.2	2.1	0.1	96.6
Standing Dry Matter				
5/15	1.2	2.6	<0.1	96.2
6/30	1.4	1.7	<0.1	96.8
8/27	0.4	2.1	<0.1	97.5
10/2	1.9	0.7	<0.1	97.4

TABLE 7: OILS, POLYPHENOLS AND HYDROCARBONS
WEST BILLINGS SITE

YIELD (% dry weight) Harvest Date & Biomass Type	Oils	Polyphenols	Hydrocarbons	Residue
Aboveground				
6/28	2.4	2.9	0.2	94.5
8/30	1.6	5.9	<0.1	92.5
10/9	1.0	2.4	<0.1	96.6
Live Rhizomes				
4/24	0.9	4.8	0.1	94.2
6/28	2.2	2.7	0.1	95.0
8/30	0.9	6.8	<0.1	92.3
10/9	2.0	3.1	<0.1	94.9
Dead Rhizomes				
4/24	1.1	3.2	0.1	95.6
6/28	1.6	1.6	0.1	96.7
8/30	1.0	1.7	<0.1	97.3
10/9	1.0	1.2	<0.1	97.8
Standing Dry Matter				
4/24	0.9	2.5	0.1	96.5
6/28	1.1	1.8	0.1	97.0
8/30	0.7	1.0	<0.1	98.3
10/9	1.6	1.0	<0.1	97.4

TABLE 8: LIGNIN CONTENT[1]

	LIGNIN (% dry weight)			
Site	Aboveground Biomass	Live Rhizome	Dead Rhizome	Standing Dry Matter
Park City	49.7	25.3	48.1	48.5
West Billings	44.0	25.7	42.4	49.5

[1] Based on samples from last harvest: Park City 10/2/82; West Billings 10/9/82

TABLE 9: CRUDE FIBER CONTENT[1]

Site	Aboveground Biomass	Live Rhizome	Dead Rhizome	Standing Dry Matter
	CRUDE FIBER (% dry weight)			
Park City	36.9	16.2	23.3	37.7
West Billings	33.7	16.0	25.5	38.3

[1] Based on samples from last harvest: Park City 10/2/82; West Billings 10/9/82

TABLE 10: ASH[1]

	ASH CONTENT (% dry weight)			
Site	Aboveground Biomass	Live Rhizome	Dead Rhizome	Standing Dry Matter
Park City	5.5	5.5	7.6	5.4
West Billings	10.0	9.6	14.5	11.3

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[1] Based on samples from last harvest: Park City 10/2/82; West Billings 10/9/82

TABLE 11: TOTAL SUGARS (REDUCING and NON-REDUCING)

SUGAR (% dry weight)

Site	Harvest Date	Aboveground Biomass	Live Rhizome	Dead Rhizome	Standing Dry Matter
Park City	5/15	-	8.0	-	-
	6/30	0.5	7.0	-	-
	8/27	2.7	10.2	-	-
	10/2	1.0	7.1	1.0	0.6
West Billings	4/24	-	6.4	-	-
	6/28	0.8	3.5	-	-
	8/30	1.0	5.8	-	-
	10/9	2.2	5.9	0.6	0.1

TABLE 12: STARCH

		STARCH CONTENT (% dry weight)			
Site	**Harvest Date**	**Aboveground Biomass**	**Live Rhizome**	**Dead Rhizome**	**Standing Dry Matter**
Park City	5/15	-	17.7	-	-
	6/30	8.0	21.5	-	-
	8/27	16.5	20.4	-	-
	10/2	7.7	21.9	8.5	7.7
	8/27	-	28.3 (Less Roots & Leaf Bases)		
West Billings	4/24	-	19.1	-	-
	6/28	4.1	12.9	-	-
	8/30	4.8	19.5	-	-
	10/9	3.4	23.9	3.9	3.4

TABLE 13: PROTEIN

Site	Aboveground Biomass	Live Rhizome	Dead Rhizome	Standing Dry Matter
	PROTEIN[1,2] (% dry weight)			
Park City	4.9	5.4	2.3	1.6
West Billings	6.7	9.8	5.9	3.1
Mean	5.8	7.6	4.1	2.4

[1] A conversion factor of 6.25 was arbitrarily used to estimate protein values from Kjeldahl nitrogen determinations. This conversion factor is also used to estimate protein in corn and sorghum (Horwitz 1980).

[2] Based on samples from last harvest: Park City 10/2/82; West Billings 10/9/82

TABLE 14: STANDING CROP YIELD OF EXTRACTABLES AND RESIDUE[1]

	YIELD (kg per hectare)						
Biomass	**Oils**	**Polyphenols**	**Total Sugars**	**Starch**	**Protein**	**Crude Fiber**	**Lignin**
Park City							
Aboveground	92	231	129	508	323	2435	3280
Live Rhizomes	206	2812	1832	5650	1393	4180	6527
Dead Rhizomes	107	187	89	757	205	2074	4281
Standing Dry Matter	283	104	89	1147	238	5617	7227
Total	688	3334	2139	8062	2159	14,306	21,315
West Billings							
Aboveground	129	310	284	439	864	4347	5676
Live Rhizomes	406	629	1198	4811	1989	3248	5217
Dead Rhizomes	49	59	29	191	289	1250	2078
Standing Dry Matter	37	23	2	78	71	881	1139
Total	621	1021	1513	5519	3213	9726	14,110
Mean Yield Both Sites							
Aboveground	111	271	207	474	594	3391	4478
Live Rhizomes	306	1721	1515	5231	1691	3714	5872
Dead Rhizomes	78	123	59	474	247	1662	3180
Standing Dry Matter	160	64	46	613	155	3249	4183
Total	655	2178	1826	6791	2686	12,016	17,713

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[1] Calculations based on content and yield data from October harvests.

TABLE 15: ANNUAL CROP YIELD OF EXTRACTABLES AND RESIDUE[1]

	YIELD (kg per hectare)						
Biomass	**Oils**	**Polyphenols**	**Total Sugars**	**Starch**	**Protein**	**Crude Fiber**	**Lignin**
Aboveground	118	289	157	544	568	3460	4591
Live Rhizomes	204	1022	949	3343	1153	2350	1876
TOTAL	322	1311	1106	3887	1721	5810	6467

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[1] Values were calculated as the product of productivity (Table 5) x mean percentage of extractive or residue obtained for the last harvest date (Tables 6-9).

TABLE 16: POTENTIAL ETHANOL YIELD FROM STANDING CROP

	STANDING CROP YIELD (kg per hectare)		ETHANOL YIELD[1] (gallons per hectare)		
Biomass	Sugars	Starch	From Sugars	From Starch	Total Ethanol
Aboveground	207	474	33	75	108
Live Rhizomes	1515	5231	239	824	1063
Total	1722	5705	272	899	1171

[1] 6.35 kg sugar or starch = 1 gallon ethanol

TABLE 17: POTENTIAL ETHANOL YIELD BASED ON ANNUAL PRODUCTIVITY

	PRODUCTIVITY (KG per hectare)[1]		ETHANOL YIELD (Gallons per hectare)		
Biomass	Sugars	Starch	From Sugars	From Starch	Total Ethanol
Aboveground	175	740	28	117	145
Live Rhizomes	927	3346	146	527	673
Total	1102	4086	1745	644	818

[1] Annual productivity for aboveground biomass = mean standing crop for the October harvests at Park City and West Billings. For live rhizomes, annual productivity = mean value of the maximum standing crop of aboveground biomass (14.6 m.t. · ha^{-1}) x mean starch or sugar content for the October harvest at each site.

TABLE 18: Potential Ethanol Yield of Selected Montana Crops (from Wiatr 1985)

Crop	Annual Ethanol Yield (Gallons Per Hectare)
Sugar beets	1132-1851
Fuel beets	1305-2293
Corn	497-561
Wheat	151-205
Barley	208-245

TABLE 19: COMPARATIVE MASS YIELD

YIELD (d.w. tonnes per hectare)

Plant	Year	Crop	Fermentable Carbohydrate	Residual Biomass		Total
		RHIZOME		RHIZOME	LEAVES	
Cattail[1]	1982	16.1	4.7	11.3	10.7	26.8
Sugar Beet[2]		ROOT	ROOT PULP	LEAVES		
HH30	1982	18.6	14.3	4.3	4.5	23.1
GW MonoHy D7	1982	18.6	13.5	4.1	4.2	22.8
GW MonoHy D2	1982	17.5	13.0	4.4	4.2	22.5
Fuel Beet[2]		ROOT		ROOT PULP	LEAVES	
Meka Otofte	1982	21.0	15.8	5.2	4.2	25.2
Krake	1982	20.5	16.0	4.4	5.2	25.7
Monriac	1982	20.0	14.1	5.9	2.7	22.7
Grain[2]		GRAIN	FROM GRAIN	STRAW/STOVER		
Barley	1977-79	2.3	1.6	0.8	5.6	8.0
Wheat	1977-79	2.0	1.2	0.5	4.7	6.7
Corn	1977-79	5.0	3.7	1.3	5.5	10.5

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[1] Values given are estimates of annual productivity, Rhizome yield = Maximum seasonal yield of aboveground biomass. Fermentable carbohydrate yield = mean yield of starch + sugars for both sites based on starch/sugar content in October. Leaf yield = mean aboveground biomass yield for both sites in October.

[2] From Wiatr 1985.

TABLE 20: CALORIFIC VALUES

	CALORIFIC VALUE (cal per gram)						
	Biomass				Extractives		
Site	Aboveground	Live Rhizome	Dead Rhizome	Standing Dry Matter	Oils	Polyphenols	Residue
Park City	4083	3880	4072	4085	8328	5617	4094
West Billings	3932	3546	3700	3848	8789	5692	3782
Mean	4008	3713	3886	3967	8559	5655	3938

TABLE 21: STANDING CROP ENERGY YIELD BY BIOMASS TYPE

		Energy (10^7 Kcal/per hectare)				Total	
Site	**Harvest Date**	**Aboveground Biomass**	**Live Rhizome**	**Dead Rhizome**	**Standing Dry Matter**	**All Biomass**	**Aboveground Biomass & Live Rhizome**
Park City	5/15/82	-	11.7	3.4	7.8	23.0	11.7
	6/30/82	1.2	11.1	4.5	7.1	23.8	12.2
	8/27/82	4.7	9.8	4.0	5.4	23.9	14.5
	10/2/82	2.7	10.0	3.6	6.1	22.4	12.7
West Billings	4/24/82	-	8.0	1.7	1.7	11.3	8.0
	6/28/82	1.1	8.9	1.6	2.7	14.3	10.0
	8/30/82	6.9	6.3	1.4	6.9	15.3	13.3
	10/9/82	5.1	7.2	1.8	8.9	15.0	12.3

TABLE 22: ENERGY YIELD AND APPORTIONMENT BY EXTRACTIVE
PARK CITY SITE

ENERGY YIELD (10⁶ Kcal/per hectare)

Harvest Date	Aboveground Biomass	Live Rhizome	Dead Rhizome	Standing Dry Matter	Aboveground biomass & Live Rhizome	All Biomass
OILS						
5/15/82	-	3.3	0.4	1.9	3.3	5.5
6/30/82	0.4	2.8	0.8	2.0	3.3	6.1
8/27/82	0.9	3.2	0.9	0.4	4.0	5.4
10/2/82	0.8	1.7	0.9	2.4	2.5	5.7
SEASONAL GAIN(LOSS)	0.8	(1.6)	(0.5)	(0.5)	(0.8)	0.2
POLYPHENOLS						
5/15/82	-	19.6	1.4	2.8	19.6	23.7
6/30/82	0.5	16.2	1.1	1.7	16.7	19.4
8/27/82	4.6	11.7	0.9	1.6	16.2	18.7
10/2/82	1.3	15.8	1.1	0.6	17.1	18.7
SEASONAL GAIN(LOSS)	1.3	(3.8)	(0.3)	(2.2)	(2.5)	(5.0)
RESIDUE						
5/15/82	-	107.9	33.1	75.2	107.9	216.2
6/30/82	11.2	103.3	43.7	68.7	114.4	226.8
8/27/82	43.0	68.9	39.2	53.0	136.7	228.8
10/2/82	25.6	93.2	35.3	59.4	118.8	213.4
SEASONAL GAIN(LOSS)	25.6	(14.7)	2.2	(15.8)	10.9	(2.8)

Harvest Date	Aboveground Biomass & Live Rhizome	All Biomass
5/15/82	130.7	245.5
6/30/82	134.3	252.3
8/27/82	132.3	252.9
10/2/82	138.3	237.9
NET ENERGY GAIN (LOSS)	7.6	(7.6)

TABLE 23: ENERGY YIELD AND APPORTIONMENT BY EXTRACTIVE WEST BILLINGS SITE

ENERGY YIELD (10^6 Kcal/per hectare)

Harvest Date	Aboveground Biomass	Live Rhizome	Dead Rhizome	Standing Dry Matter	Aboveground biomass & Live Rhizome	All Biomass
OILS						
4/24/82	-	1.8	0.5	0.3	1.8	2.6
6/28/82	0.6	4.9	0.6	0.7	5.4	6.7
8/30/82	2.5	1.4	0.3	0.1	3.9	4.3
10/9/82	1.1	3.6	0.4	0.3	4.7	5.5
SEASONAL GAIN(LOSS)	1.1	1.8	(0.1)	0	(2.9)	(2.9)
POLYPHENOLS						
4/24/82	-	6.1	0.9	0.6	6.1	7.6
6/28/82	0.4	3.9	0.4	0.7	4.3	5.4
8/30/82	6.0	6.9	0.4	0.1	12.9	13.3
10/9/82	1.8	3.6	0.3	0.1	5.3	5.8
SEASONAL GAIN(LOSS)	1.8	(2.5)	(.6)	(0.5)	(0.8)	(1.8)
RESIDUE						
4/24/82	-	79.9	16.9	15.7	79.9	112.4
6/28/82	9.7	90.2	15.7	26.1	99.9	141.7
8/30/82	71.9	62.3	13.7	6.7	124.2	144.5
10/9/82	47.1	72.7	18.2	8.5	119.8	146.5
SEASONAL GAIN(LOSS)	47.1	(7.2)	1.3	(7.2)	39.9	34.1

Harvest Date	Aboveground Biomass & Live Rhizome	All Biomass
4/24/82	87.8	122.6
6/28/82	109.6	153.9
8/30/82	151.0	162.2
10/9/82	129.9	149.1
NET ENERGY GAIN (LOSS)	42.1	35.2

TABLE 24: COMPARATIVE ENERGY YIELDS

ENERGY YIELD (x 10^7 Kcal per hectare)

Crop	Year	Fermentable Carbohydrate	Residual Biomass		Total
			Rhizome	Leaves	
Cattail[1]	1982	1.7	4.0	3.9	9.6
Cattail[2]	1982	2.7	5.9	3.9	12.5
Sugar Beet Cus.[3]			Root Pulp	Leaves	
HH30	1982	5.1	1.1	1.5	7.8
GW MonoHy D7	1982	4.8	1.1	1.4	7.3
GW MonoHy D2	1982	4.6	1.2	1.4	7.3
Beta KW 834	1982	4.6	1.4	1.4	7.4
Fuel Beet Cus.[3]			Root Pulp	Leaves	
Meka Otofte	1982	5.7	1.4	1.5	8.5
Krake	1982	5.7	1.2	1.5	8.4
Monriac	1982	5.0	1.7	0 9	7.6
Cereal Grains[3]			From Grain	Straw/Stover	
Barley	1977-79	0.7	0.1	2.4	3.2
Wheat	1977-79	0.4	0.2	1.7	2.3
Corn	1977-79	1.3	0.3	2.4	4.0

[1] Based on annual productivity of rhizomes (= maximum standing crop of aboveground biomass). Fermentable carbohydrate = Starch + Sugars from rhizomes.

[2] Based on mean standing crop of October harvests at Park City and West Billings.

[3] From Wiatr 1985.

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APPENDIX

Sugars -Comminuted biomass samples (0.5g) were extracted with 80% ethanol for 24 hrs at room temperature. After ethanol removal, insoluble residue in the aqueous samples was removed by centrifugation at 500g for 10 min. The supernatant was then decanted and further clarified with neutral lead acetate (AOAC 3.105a in Horwitz 1980). Excess lead was removed by adding solid sodium oxalate crystals until no further cloudiness due to lead oxalate was apparent. Aliquots of this solution were assayed for reducing sugars by the Somogyi titrimetric method (AOAC 3.120 in Horwitz 1980). To assay for non-reducing sugars, aliquots were first inverted with 3N HCl for 48 hrs at room temperature, then neutralized with 2N sodium carbonate. Neutral, inverted solutions were assayed for reducing equivalents as in AOAC 3.120 above. Non-reducing sugar content was the difference in reducing strength expressed in glucose equivalents determined before and after inversion.

Starch -Starch determinations were made using a modified procedure derived from AOAC 3.120 (Horwitz 1980). Samples of dried biomass (usually 0.5g) were boiled in a small volume of water to gelatinize the starch, after which the starch was solubilized in 30% perchloric acid. Protein in the samples was removed by precipitation with 1.7% uranyl acetate. Solubilized starch in the protein-free samples was precipitated with iodine-potassium idodide solution in 3% NaCl. After several washings in alcoholic NaCl, the starch-iodine complex which had formed was decomposed with alcoholic NaOH. The liberated starch was washed several times with alcoholic NaCl and subsequently hydrolyzed in 0.7N HCl in a water bath for 2.5 hr. The acid solution was neutralized with NaOH and an aliquot was

taken for reducing sugars as above. Known standards of soluble potato starch were used to determine starch content in the biomass samples.

Oils, polyphenols, and hydrocarbons -Four to six replicates of comminuted biomass samples, each weighing 15-30g, were sequentially extracted in a Soxhlet apparatus for 24-48 hrs using the method of Buchanan et al (1978). Acetone extractives were obtained first and these were partitioned between hexanes to extract oils and 87.5% EtOH to extract polyphenols. The residue remaining after acetone extraction was dried in a 55 C oven and later extracted with cyclohexane to obtain a hydrocarbon fraction. Initially, the solvents were removed from oils, polyphenols, and hydrocarbons by evaporation in a Buchi rotary evaporator. The residues were then quantitatively transferred to evaporating dishes and allowed to dry further at 40 C. Weights were determined gravimetrically and expressed on both a dry and fresh weight basis.

Lignin -The dried residue remaining after acetone and cyclohexane extraction was used for lignin determinations following a modification of the indirect-method given in AOAC 3.126 (Horwitz 1980). One gram samples were washed sequentially with ethanol and ether, dried, and digested over night at 40 C in 1% pepsin in 0.1N HCl. The residue was filtered, washed, and refluxed for 1 hr in 5% H_2SO_4 then held for 2 hrs at 25 C in 72% H_2SO_4 and refluxed again for 2 hrs in 3% H_2SO_4. The residue remaining after acid digestion was washed and dried at 100 C. Lignin content was determined by loss in weight on ignition at 600 C.

Crude fiber -Crude fiber content was determined using a modified acid-alkali digestion as given in AOAC 7.068 (Horwitz 1980). One gram samples of oil and hydrocarbon-free residue were sequentially refluxed for 30 mins in 1.25% H_2SO_4 and 1.25% NaOH. After a final was in 1.25% H_2SO_4

and several rinses of boiling water, the residue was dried overnight at 100 C.

Protein -Total nitrogen in biomass was determined by direct Nesslerization of ammonia produced by sulfuric acid and hydrogen peroxide digestion (Dotti and Orten 1971). Nitrogen content was determined calorimetrically and expressed as percent protein using a conversion factor of 6.25 as is used for corn and sorghum (AOAC 14.068 in Horwitz 1980).

Calorimetry -The energy content of whole leaf tissue, extractives and residual biomass was determined with a Parr model 1241 adiabatic oxygen bomb calorimeter. Corrections were made for the heat of formation of nitric acid and heat of combustion of the fuse wire. A thermochemical correction for the heat of formation of sulfuric acid was not included since preliminary analyses indicated that the sulfur content was negligible.

Statistics -Statistical comparisons were made using a modified least significant difference (LSD) procedure or Tukey's Honest Significant Difference procedure for multiple comparisons with an SPSS program on a DEC system 20/60. All comparisons were made at the 5% level of significance.